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Glass Wastes-Reinforced Brake Pad Composite for Enhanced Friction Stability

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ABSTRACT

The purpose of this study was to investigate the use of waste glass powder as a reinforcement for composite brake friction materials. Samples were prepared by pressing at 250°C for 2 hours. To obtain brake linings with good performance, the glass powder fraction was varied from 9.9% vol to 29.9% vol. The quality of the friction material was determined through characterization and testing, including hardness, wear, density, thermal resistance, and surface structure. The results showed that the specimen with 29.9 vol% glass powder achieved the highest performance, with a hardness of 80 HRB, a wear rate of 0.63 × 10^{-4} mm^2/kg, a density of 2 g/cm^3, and thermal resistance up to 500 °C.

Keywords: *Brake pad, Composite, Glass Powder, Reinforcement material, Waste*

1. INTRODUCTION

Industrial development without adequate waste management will lead to environmental, social, and health problems [1]. Waste consists of organic and inorganic materials. One example of inorganic waste is glass. Glass waste originates from various sources, including used household items, vehicles, furniture, industrial equipment, and medical devices [2]. Global glass production amounted to 77 million tons in 2014 [3]. The use of glass products is increasing daily. This is driven by their advantages, including good optical transparency, resistance to chemicals and moisture, high intrinsic strength, and low gas permeability [4]. Glass waste can be recycled and transformed into industrial raw materials to produce new and valuable products [3].

Glass waste can be processed into one of the raw materials for making composite brake pads [5]. Glass fiber can enhance the surface hardness of friction materials and the wear resistance of brake pads when operating at temperatures below the glass transition temperature [6], [7]. The addition of glass fiber can also enhance the strength [8] and the elastic modulus of composite materials, thereby increasing their resistance to crack propagation [9].

On the other hand, glass fibers can reduce the flexural strength of friction materials [10], due to their low tensile modulus [11]. Both glass fibers and glass powder have nearly identical properties, as glass powder is the raw material for making glass fibers [12]. The hardness of brake pad friction materials can be increased by incorporating fine-particle glass powder as a component [13].

2. MATERIALS AND METHOD

The brake lining components consist of: (1) Binder, bakelite (Vechem Organics (P) Ltd., India); (2) SBR preservative including sulfur, stearic acid, and zinc oxide (Indo Lysaght, Indonesia); and (3) Filler metal powder (brass, bronze, and stainless steel), calcium carbonate (Omyacarb, Australia), glass powder, and magnesium oxide (Unicarb, Niraku Jaya Abadi, Indonesia) [14], [15].

Brake pad samples were made using a mold that adapts to 110 CC motorcycle disc brake pads, in accordance with the Indonesian National Standard (SNI 09-0143-1987), and were molded using a hot isostatic pressing technique at a temperature of 250 °C with a load of 6-10 metric tons for 2 hours [16].

Friction testing was conducted using the high-speed 9.5-cm-radius metal brake disc loading method, which employed a 933 W motor in the Material Physics Laboratory of the Physics Department at Semarang State University. The test load ranged from 5 to 13 kg in 2 kg increments, applied perpendicular to the surface.

The specifications of the successfully produced brake pads were 18–20 g in mass and 0.6–0.7 cm in thickness. The properties of the brake pads, as determined by characterization and testing, including hardness, wear resistance, density, thermal resistance, and surface morphology, are discussed in the following section [7].

2.1. Rockwell Ball Hardness Test

The results of the composite brake pad hardness test are shown in Figure 1, which indicates that the addition of glass powder fraction has increased the hardness of the composite brake pad. The hardness of the composite brake pad follows a positive exponential pattern, increasing from 75 HRB at 9.9% vol glass powder to 89.5 HRB at 29.9% vol. The relatively high glass powder content, reaching almost 30% vol, contributes to increased density and hardness [17].

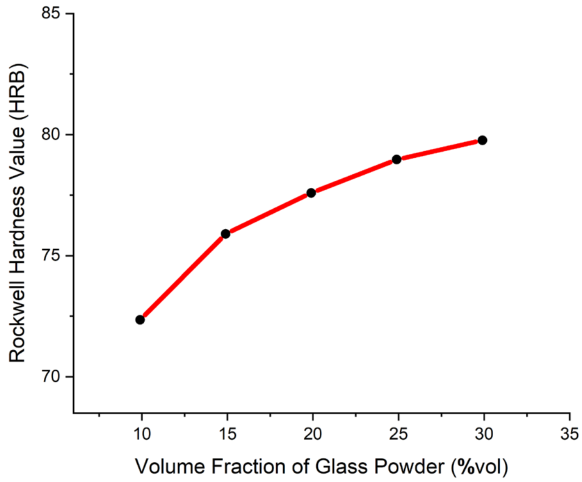

Figure 1. Effect of increasing the volume fraction of glass powder on the Rockwell Hardness.

Glass has a high hardness of 179-229 HBN, which significantly contributes to the overall hardness of composite brake pads [18]. During hot pressing, each component of the brake pad deforms, resulting in variations in the brake pad's properties. Finer reinforcement particle sizes increase density and reduce micro-voids. The size of commercial metal powders on the market, ≤ 100 mesh (149 μm), is still relatively large, so glass powder with a finer size of ≤ 200 mesh (74 μm) is required [19].

2.2. Wear Ogoshi Test

The wear value of the resulting composite brake pads ranges from 4.22×10^{-4} mm²/kg to 0.63×10^{-4} mm²/kg, as shown in Figure 2. Higher glass powder content indicates higher brake pad wear resistance. The effect of glass powder in increasing brake pad wear resistance can be explained by the fact that, during friction between the brake pad surface and the disc surface, the hard glass powder plays a crucial role. Soft materials will be easily eroded by hard materials [20]. Fine glass powder increases material densification.

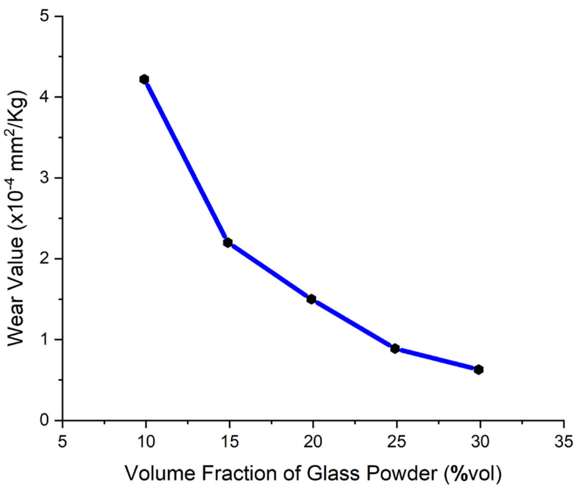

Figure 2. Effect of increasing the volume fraction of glass powder on the Wear value.

Harder materials tend to be more resistant to wear. Wear behavior is also influenced by the adhesion forces between particles. Wear testing techniques differ from those used in hardness testing. Hardness testing is performed in a perpendicular orientation, while wear testing is performed in a parallel orientation, resulting in gradual particle erosion. This difference in pressure orientation results in varying amounts of pressure applied to the disc surface [21].

2.3. Density Measurement

The composite containing 29.9% vol glass powder showed the lowest density, at 2.0 g/cm^3, as shown in Figure 3. In comparison, the specimen containing 9.9% vol glass powder showed a higher density, at 2.4 g/cm^3. The coarse and non-uniform glass powder makes it difficult to fill the cavities in the composite brake lining.

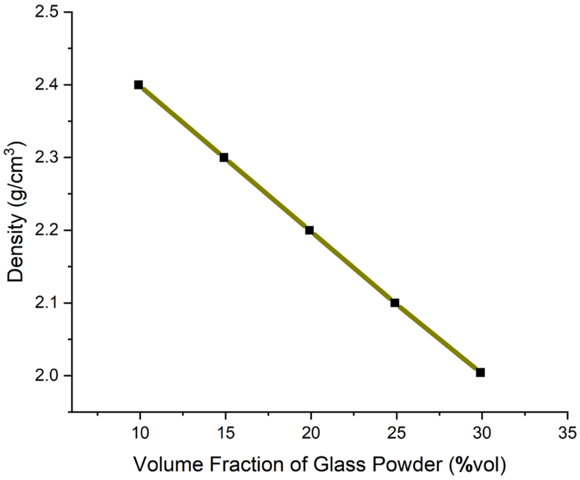

Figure 3. Effect of increasing the volume fraction of glass powder on the Density value.

Composite brake pad friction materials are multicomponent materials. The density of the composite depends on the density and fraction of each component. For example, the densities of glass powder and metal powder are 0.65 g/cm^3 and 1.21 g/cm^3, respectively, and the density of the composite is a combination of the densities of its components [22].

2.4. Thermal Resistance Test (DTA-TGA)

Figure 4 shows the DTA/TGA curve for composite brake pads with a glass powder content of 29.9 %vol. The blue line represents the change in sample weight as the temperature increases from 0 to 600°C. The red line illustrates the relationship between volume differentiation and weight as the temperature increases from 0 °C to 600 °C. The chemical reaction is thought to occur at the exothermic peak at temperatures of 336°C and 444°C. Between 218°C and 507°C, the specimen is assumed to undergo softening and oxidation, resulting in a loss of approximately 8% by weight. The specimen maintains thermal stability up to about 500°C [23].

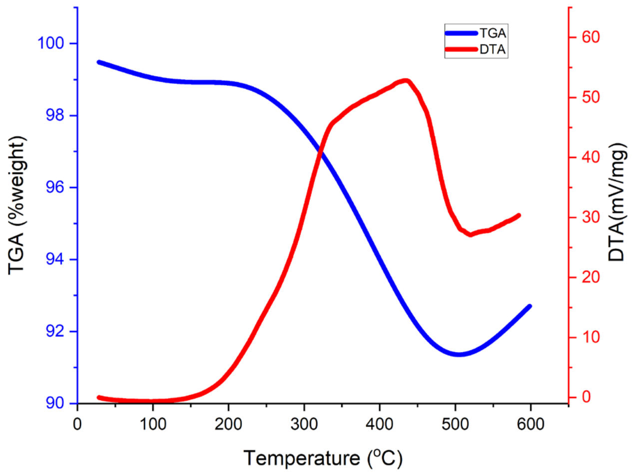

Figure 4. DTA and TGA test results for composite brake pads reinforced with 29.9%vol glass powder.

2.5. Microstructure Characterization

Figure 5 shows a 5000X magnification SEM image of the surface microstructure of a brake pad specimen with a glass powder content of 29.9% vol. This SEM image shows many grains of various sizes, indicating a multicomponent material [24]. There are circular, square, white powder, and fly ash-shaped grains [25]. The image also depicts a fluorescent object. In Figure 5, the lower region contains fewer fluorescent objects than the upper region, suggesting heterogeneous mixing of materials. The microstructure does not appear to contain many cavities [26].

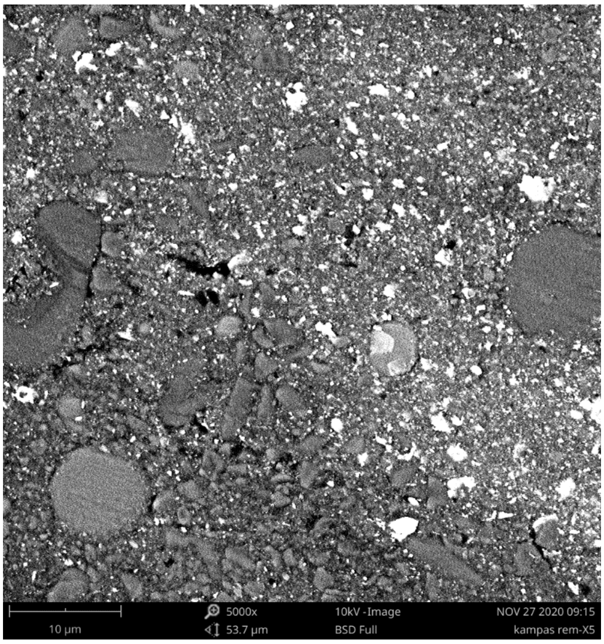

Figure 5. Surface appearance of brake pad composite reinforced with 29.9%vol glass powder with 5000x magnification.

Figure 6 shows the EDX curve. Three strong elemental peaks are Si, O, and Zn. The Si peak originates from glass powder, which is close to 30%, and the Zn peak originates from zinc oxide. In addition to glass powder, coal fly ash also contributes to the Si content. The O element naturally binds Si to form SiO_2. The metal powder material is visible due to the presence of elements such as Fe, Al, and Cu [27]. The O element naturally binds Si to form SiO_2. The metal powder material is visible due to the presence of elements such as Fe, Al, and Cu.

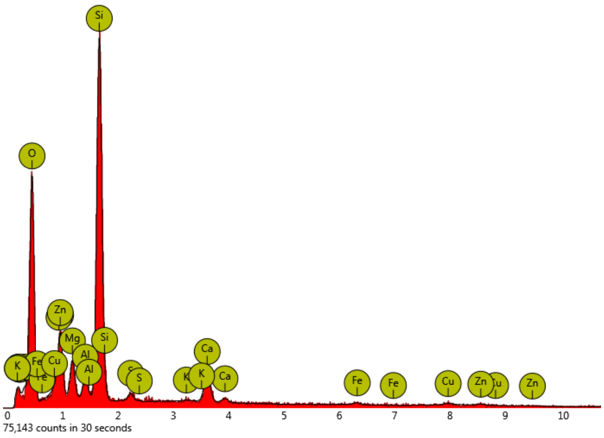

Figure 6. Curve of material content of glass powder reinforced brake pad composite 29.9 %vol.

3. RESULTS AND DISCUSSION

The friction material formulation was initially studied through simulation, followed by an experimental approach. The results of laboratory-scale simulations are summarized in Table 1. The glass powder content of the brake pad friction material specimens ranged from 9.9% to 29.9% by volume. Friction testing was conducted using a test load of 5-13 kg. The measured friction coefficient ranged from 0.29 to 0.89 [7].

Table 1 Friction coefficient values at all braking load levels

Glass Powder (%vol)	Load (kg)				
	5	**7**	**9**	**11**	**13**
9.9	0.66	0.49	0.39	0.33	0.29
14.9	0.70	0.52	0.42	0.37	0.33
19.9	0.75	0.57	0.47	0.39	0.36
24.9	0.82	0.61	0.50	0.44	0.38
29.9	0.89	0.69	0.56	0.48	0.44

Based on Table 1 and Figure 7, at a test load of 13 kg, the higher the glass powder content (9.9% vol – 29.9% vol), the higher the friction coefficient (0.29 – 0.44). For test specimens with a certain glass powder content, for example, 9.9% vol, the greater the test load (5 kg–13 kg), the lower the friction coefficient (from 0.66 to 0.29). In general, the greater the applied load, the smaller the friction coefficient [28].

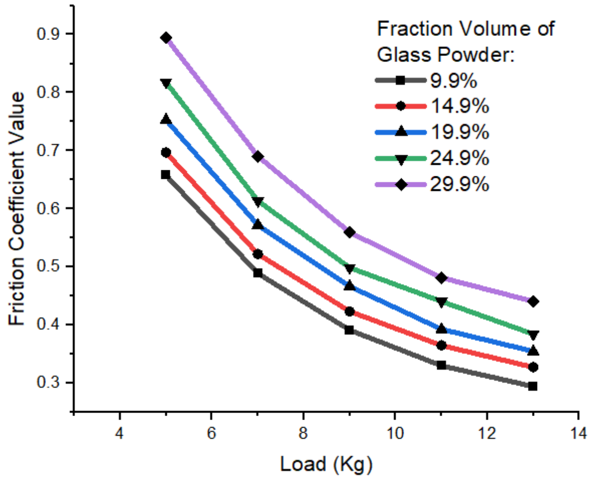

Figure 7. Friction Coefficient of brake pad composite against increasing braking load.

The transfer film layer that forms during friction depends on the type and quantity of ingredients in the brake pad. The properties of this transfer film layer are also influenced by the brake pad's composition. Coal fly ash powder or other carbon materials act as friction lubricants, reducing the coefficient of friction and preventing the two surfaces from locking.

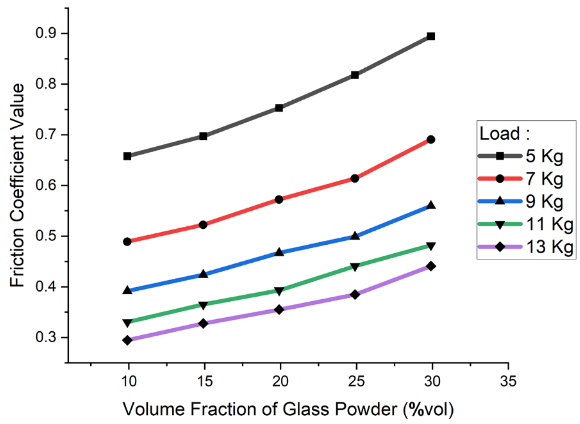

Figure 8. Friction Coefficient of brake pad composite against increasing volume fraction of glass powder.

Based on Figure 8, the higher the volume fraction of glass powder, the higher the brake pad friction coefficient. Glass is a material with relatively high hardness and wear resistance, thus playing a crucial role during the friction mechanism [29].

Due to facility limitations, the friction coefficient test did not account for temperature and humidity during braking. There are two temperatures: room temperature and the brake pads' operating temperature. The brake pad friction test was conducted at room temperature. The ambient temperature and humidity were assumed to be constant. Increasing the brake pad operating temperature can accelerate material erosion when the pad contacts the disc plate. Therefore, further research is recommended to consider the aspects of operating temperature and ambient humidity.

4. CONCLUSION

Glass powder, a component of brake pads, has been shown to significantly increase hardness, wear resistance, and the friction coefficient. Test results show that the composite brake pad specimens have met the standards set in SNI 9370:2025. The results of DTA/TGA analysis show that the brake pads exhibit good stability up to 500°C.

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